UMR GAEL Laboratoire d'Economie Appliquée de Grenoble

TECHNOLOGICAL AGGLOMERATION AND THE EMERGENCE OF CLUSTERS AND NETWORKS IN NANOTECHNOLOGY

ROBINSON Douglas K.R. ; RIP Arie ; MANGEMATIN Vincent

Working Paper GAEL ; 2006-05

- March 2006 -

Institut National de la Recherche Agronomique - Université Pierre Mendès France
Unité Mixte de Recherche 1215
Domaine Universitaire - BP 47 - 38040 GRENOBLE Cedex 9
Tél. : 33 (0) 4 76 82 54 39 - Fax : 33 (0) 4 76 82 54 55
E-mail : vertier@grenoble.inra.fr - http://www.grenoble.inra.fr

TECHNOLOGICAL AGGLOMERATION AND THE EMERGENCE OF CLUSTERS AND NETWORKS IN NANOTECHNOLOGY

Douglas K. R. Robinson, Arie Rip and Vincent Mangematin

Abstract

Based on the analysis of two clusters in nanotechnologies (MESA+ in the Netherlands and Minatec in Grenoble in France), the paper examines the emergence and effects of technological agglomeration: The social and technical arrangements of a regional centres for nanotechnology both enable and constrain the ongoing activities and research lines that can be followed. Technology platforms and their co-location are a pre-requisite for nanotechnology research and agglomeration of such platforms are both a means and outcome for institutional entrepreneurs to mobilise resources, build networks and construct regional centres of excellence in nanotechnology. Technological agglomeration shapes the networks that evolve and leads to the convergence of scientific disciplines.

Keywords: technological agglomeration, technology platform, multilevel activities, cluster, district, converging technology.

March 2006

1 Introduction

There is a rich literature on clusters and districts, case studies have been done, comparisons have been made, and general (even if tentative) conclusions have been formulated, e.g. the role of centres of excellence and star scientists (Zucker, 2002, Zucker, 1998), the size of the existing market (Feldman, 2001, Autant-Bernard, 2006) or the role of incumbents and large firms (Agrawal and Cockburn 2003). These analyses have often focused on biotechnology.

What has been neglected is what we will call ‘technological agglomeration’ in this paper: technological opportunities as well as technological requirements stimulate linkages, coordination, and cumulative advantages, and thus afford as well as specify agglomeration of actors and activities in a geographical region, and more generally, in clusters building on proximity. This general characterization of technological agglomeration may be developed further, and lead to specific hypotheses, for example about the changing composition of the workforce linked to shifts in competencies in the cluster. In this paper, however, we limit ourselves to explore the phenomenon of technological agglomeration in two concrete cases.

Technological agglomeration is a general phenomenon, but it is particularly visible in newly emerging nanotechnology-linked developments. We will use our ongoing studies of regions with a high concentration of nanotechnology-linked activities to show the importance of technological agglomeration for the overall dynamics of development. This will also allow us to further articulate the phenomenon of technological agglomeration. In particular, there turns out to be a difference between the strongly structured requirements, on technology and on actors and their interactions, for a next generation in micro/nano-electronics, and the open-ended and partially overlapping technological opportunities and networked linkages in the areas of nanomaterials and nanobiotechnology.

Our analysis of these techno-institutional dynamics and related changes in industrial networks, including regional actors and policy makers, will build on the phenomenon of technology platforms, and the increasing recognition of their importance in supporting innovation, as a key part of business models of (high-tech) start-ups, and as having dynamics and requirements of their own they are not just exogenously available.

We use this approach to understand the role of technological agglomeration in the evolution of nano-clusters in the Netherlands and in Grenoble. What we see there also refers to changes in industrial networks, and to the role of authorities at different levels.

Section 2 underlines how critical technology platforms are in nanotechnologies R&D. Section 3 analyses the dynamics of formation of technological agglomeration as well as the clustering effects induced. Sections 4 and 5 explore two different organisational arrangements in MESA+ (the Netherlands) and Grenoble (France) while section 6 discusses the agglomeration effects of technological agglomeration.

2. Nanotechnology and technology platforms

The past 5 years has seen an explosion of interest for the area of science and technology labelled "nanotechnology." Although at an early stage, promises have led to high expectations of the fruits that could be harvested from the development and investment into nanotechnology. Unlike previous high-technology hypes,[1] nanotechnology covers a diverse field of sciences and engineering, crosses boundaries between them and aims to utilize the very fundamental characteristics of matter by manipulation and control at the nanoscale.

This control of matter first became possible with the invention of atomic force microscopy (AFM) and scanning tunnelling microscopy (STM) by IBM. This enabled both characterisation of nano-properties of materials as well as manipulation and construction of nanomaterials and structures. The AFM for example remains a crucial tool for characterisation in nanotechnology as well as various additions and alterations of AFM in the form of dip-pen lithography, nano-cantilever biosensing, positioning of quantum dots etc.

Nanotechnologies are defined as technologies which include components that have at least one dimension between 1-100 nm, and display unique characteristics due to being at this scale. Thus nanotechnology, crossing many disciplines, also crosses many industries and technology chains. It covers the ever decreasing miniaturisation of computer chips from microelectronics to nanoelectronics (below 100nm), it covers thin films, membranes, functionalised surfaces, bio-detection systems, DNA analysis, optical transmission, spin storage (using rather than the macro-magnetism of a material as the method of storage but the electron spin itself).

Many fields, such as the semiconductor-chip industry and filtration sciences where moving towards nanoscale already, determined by the technology roadmaps in place and the functionalities sought for. For other research agendas, the coming of the nanotechnology label meant sources of funding, new opportunities, new areas of science to explore etc. – i.e. the stuff of hype cycles.

---

[1] We use the term "hype" descriptively here, not judging the interest and high expectations as unfounded.

With nanotechnology however, large investments into infrastructure were necessary and new organisational arrangements needed to be made. For instance bigger and better clean rooms, atomic force microscopes for observation and manipulation at the nanoscale, e-beam lithography and nano-imprint lithography to make the channels, pores, and circuits needed for the research. Organisationally, it requires the sharing of facilities, equipment and skilled technicians for these very different technology/research fields. This is a first and important feature of nanotechnology: for scientific research and technology development at the nanoscale one needs similar tools (and due to complexity of equipment also the same skilled technicians/scientists).

Also, recalling that facilities are expensive and take some time to construct, these sort of facilities for any field of nanotechnology needs high investment (both financially and in training of manpower) over a period of time. An example would be the state-of-the art Extreme Ultra-Violet lithography platform which is priced in the order of $40 million.[2]

Developments in most fields of nanotechnologies are tied to technical facilities, that is the instrumentation itself and the skills that are needed to operate them. In addition, a lot of nanotechnology research involves development, construction and implementation of new instruments be it specialised atto-second pulse lasers or dip-pen lithography with adapted AFM.

This is not just a matter of infrastructural requirements. The infrastructures add up to a basic set which allows a variety of further work. That is why we use the notion of a technological platform: it allows exploration and exploitation of a variety of options, for strategic research, technology development, and sometimes also product development. Such a basic set of technical infrastructure is somewhat independent of the team which originally built and assembled it. It is recognized by others as important, and assembled to be able to profit from the variety of purposes it can be put to. In a sense, it represents a business model *i.e.* "something that depicts the content, structure and governance of transactions designed as to create value through the exploitation of business opportunities" (Amit et al. 2001). It is not focused, however, on appropriating part of the value added in producing goods or services, but to enable innovation and valorisation (and appropriate the resulting technological options, for example in publications, patents, and as core competence of a start-up firm).

---

[2] EUV lithography takes shape at ASML, Solid State Technology, December 2005, www.solidstate.com

In fact, a technology platform is not just a collection of equipment. It "organizes" further actions, enables and constrains them. Furthermore, the recognition of the possibility of such platforms incites actions to realize them. There is emerging institutionalization of the approach *via* platforms. A sector can now be looked at not in terms of a dominant design and related industry structures, but as a patchwork of technology platforms and related coordination, up to aggregation. Technology platforms are enablers of R&D, of families of technological options, and of successive product development.

In nano R&D, as we indicated already, the range runs from the basic set necessary for manipulating at the nanoscale (STM, AFM, surface analysis instrumentation, nano-fabrication including clean room facilities) to further technological (and social) infrastructure necessary for nano-production. This will be different for different types of products: coatings vs. biochips vs. nano-electronics. Note that products are not (and most often cannot) be exclusively nano: for example, micro-systems enabled by nano-inputs (components, modifications). At this end of the range, one sees technology platforms enabling product families in the traditional sense (Tatikonda 1999). What remains is that these product families are defined by the technology rather than the sector. Start-up companies basing themselves on a technology platform in the present sense can grasp opportunities in different sectors.

Technology platforms, in the sense we use it here, occur in, and are important for further development of techno-scientific fields where instrumental and other infrastructure is important, for example in high energy physics research,[3] in various areas of biomedical science (Keating and Cambrosio 2003),[4] in genomics (Peerbaye 2004),[5] but also in development and testing, for example in the space industry (cf. also the general idea of 'infratechnology', Tassey 1991).[6] Such infrastructures on which a (contained) variety of research, development, and regulation can be built are more than a 'facility', i.e. they are

---

[3] For example particle accelerators such as cyclotrons, synchrotrons and linear accelerators. See also Hackett *et al.* (2004) on nuclear fusion research.

[4] "… biomedical platforms as specific combinations of techniques, instruments, reagents, skills, constituent entities (morphologies, cell-surface markers, genes), spaces of representations, diagnostic, prognostic, and therapeutic indications, and related etiological accounts." (Keating and Cambrosio 2003, p. 4)

[5] Peerbaye's discussion of micro-arrays as technology platforms (p. 271 ff) shows the same phenomena that we highlight for technology platforms: "Les *microarrays* peuvent donc être envisages comme une veritable "plateforme", permettant le développement d'applications biomédicales et pharmaceutiques, l'avancée des connaissance scientifiques et leur valorisation économique, ainsi que la mise au point d'innovations technologiques (nouveaux procédés de fabrication des puces, prototypage de nouveaux instruments)."

[6] For example the test facilities which simulate the environment space-craft or space instrumentation will encounter, large vibration platforms, temperature and pressure labs, clean rooms etc.

more than local: not only can there be a number of them in different places, their functioning and the acceptance of their value requires recognition as well as shared conventions. Keating and Cambrosio (2003, at p. 3) note that this holds already for strategic biomedical research: "the constitution and circulation of protocols, instruments, and substances between laboratories and the establishment of conventions that allow them to be used in the generation of biomedical facts." While a technical platform can function as the core competence of a particular laboratory or firm, and creates competitive advantages, this works only because of the recognition of the nature and quality of the platform.

Peerbaye (2004) shows how genomics platforms emerged in R&D institutions and some R&D companies (e.g. micro-arrays), but took on a further feature in France when public financing was made available provided there was some geographical concentration and provisions for access ('dispositif instrumental partagé'). From our earlier discussion of nanotechnology, it is clear that there may emerge further phenomena relevant for technological agglomeration: the umbrella term of nanotechnology covers contributions from many disciplines, such as material sciences, physics, biology, biotechnology, chemistry etc., linked because of the manipulation of matter at scales between 1nm and 100nm. Thus, there will be greater variety of specific platforms, as well as of their possible combinations, technically and geographically. In a particular locality or region, a combination can be assembled and exploited that is adapted to existing competencies and networks. Our case studies show the variety: Grenoble can focus on nano-electronics and Twente on materials and sensors.

To round up this section, we note that there is another, but overlapping use of the term 'technology platform' (or just 'platform') in chips design (e.g. System-on-a-Chip (SoC), cf. Chang et al. 1999 or Gawer and Cusumano, 2002) and in chips architecture offering a basis for a variety of customer applications. Lüthje et al. (2006) provide interesting perspectives on both:

> One key element of the "SoC revolution" was design "re-use". Following older, more mature industries like automobile manufacturing, in which most of the design for a new product is re-used for earlier generations, SoC enabled new forms of "platform-based" development, designed to split the circuitry of complex semiconductors into building blocks which can be used for various types of products. The promises are substantial savings in engineering labour, increased automation of chip design, and a transition from a craft-type to an industrialized environment for the production of chip designs (Chang et al. 1999).

Platform-based chip design considerably increases opportunities for both internal and external specialization. Large integrated chip manufacturers like Intel and global electronics brand leaders like Philips can split up development work across various departments, locations, or subcontracting companies while maintaining only the key functions of system definition and integration in-house.[7]

What we see here is that platforms, of whatever kind, are always embedded in networks where there will be nodes, coordination, and strategic actions. There will be various proximity and clustering effects. Technological agglomeration may occur, but our discussion of platforms in this section does not lead to specific hypotheses about such processes and their outcomes.

3. Technological Agglomeration and the Example of Overlapping Technology Platforms

Having discussed technological platforms as intentional opportunity structures, we must also discuss how they are part of evolving (or emerging) techno-industrial networks and help structure them. This would then allow us to specify the notion of 'technological agglomeration' further.

The literature on evolving techno-industrial networks is disappointing: systematic network analysis focuses on existing structures, and can treat changes only indirectly (comparing structures over time), while network analyses which address changes directly appear to be limited to qualitative case studies (cf. Håkansson and Snehota 1995). Such case studies are retrospective, and their lessons have to be put into a broader framework to capture the learning that is possible. This is all the more important because in the real world, there are lots of prospective, anticipatory activities. These become reflexive, and anticipatory coordination

[7] Lüthje et al. continue by noting that Modularization enables outsourcing, and thus vertical specialization. But this does not introduce a market dynamics for outsourced design work, as Langlois 2001 suggests. It requires more, not less, coordination through system integrators or network flagships. They also give a number of specific examples:

"Major Integrated Device Manufacturers increasingly focus on the development of chips platforms, based on a core processor architecture leaving ample space for variations and customization for diverse applications. (…) major chipmakers have launched a growing number of platform products in recent times. TI, the world marker leader for Digital Signal Processors used in mobile phones, has two major platforms called Open Media Application Platform (OMAP) for multimedia applications and DaVinci for mobile communications. Philips created a platform named Nexperia for a wide range of applications in digital TV and consumer electronics. LSI is promoting a similar concept in ASIC chips, called RapidChip, which comes with a host of development tools to ease adaptation for its customers. The most significant shift in this context is being performed by Intel, as the company announced to abandon the Pentium brand as its flagship product in favour of a new technology platform under the name of Viiv, designed for a wide variety of multimedia applications and based on multicore processors with less power, but much greater versatility than the Pentium."

is attempted – the European Union Technology Platforms try to do that.[8] We note that the concept of 'technological agglomeration' can thus have further use by making such anticipatory activities more concrete: the concept straddles and thus connects the anticipation of technological opportunities and emerging techno-industrial networks and the clustering that occurs.

We start with a strong claim: technological agglomeration is the effect of technological platforms being set up, used and expanded. Because of the coordination (de facto through the nature of the platform, as well as intentional, e.g. when organizing access) that is involved, there is a proximity effect and some clustering will occur. We will attempt to make this claim plausible in terms of what we see happening at the level of technology platforms (in this section), and in terms of coordination and agglomeration (in the two case studies in the subsequent sections).

There are two main routes of technological agglomeration (and one may find others routes in between, a mix of the two main routes one could say).

- Bottom up, where technological opportunities and platforms get assembled by being available at the same time ("off the shelf"), and allow various exploitations. This can then be recognized for what is happening, optimized, and packaged to be used elsewhere & else when.
- Top down, where the technological opportunity has to be articulated and designed as such, which requires a concerted effort from the beginning. The second route often builds on what has been happening in the first route, in particular when a certain threshold of articulation and stabilization has been passed. The French public policy which supported the creation of technological platforms within the Genopole programme is an example of such articulation allowing further steps to be made (Peerbaye 2004).

In the bottom-up developments, existing competencies are important, and the first platforms belonging to universities, public sector organisations or firms are localised. In nanotechnologies, this is what we see very clearly in the Netherlands. At the same time, there

---

8 The EC Communication notes that, 'at the initiative of the Commission and industry, 'Technology Platforms' are being set up, which bring together companies, research institutions, the financial world and the regulatory authorities at the European level to define a common research agenda which should mobilise a critical mass of - national and European - public and private resources.' [COM(2004)353 "Science and technology, the key to Europe's future - Guidelines for future European Union policy to support research"].
Some technological sectors have already seen the various stakeholders organise themselves within this framework. There are emerging initiatives in areas such as hydrogen and fuel cells, nano-electronics, water

can be overlap and collaboration to exploit synergies. We will build on what has been happening to sketch the possible overlap, and articulate the idea of a generic technology platform.

Already in the region Twente, but definitely the Netherlands, one finds a number of nanotechnology chains (*filières*), some still only emerging. In new fields such a bottom-up fabrication, and to a certain extent bio-nanotechnology, previous arrangements are absent, or are more diffuse. A technological *filière* is not there yet, in contrast to the situation in micro/nano-electronics. Still, one sees technology platforms being constructed and exploited.

We visualize the situation for four areas of strategic research (left-hand side of Figure 1) which builds on technology platforms allowing further exploitation of technological options and applications as exemplified by the star boxes at the right-hand side.

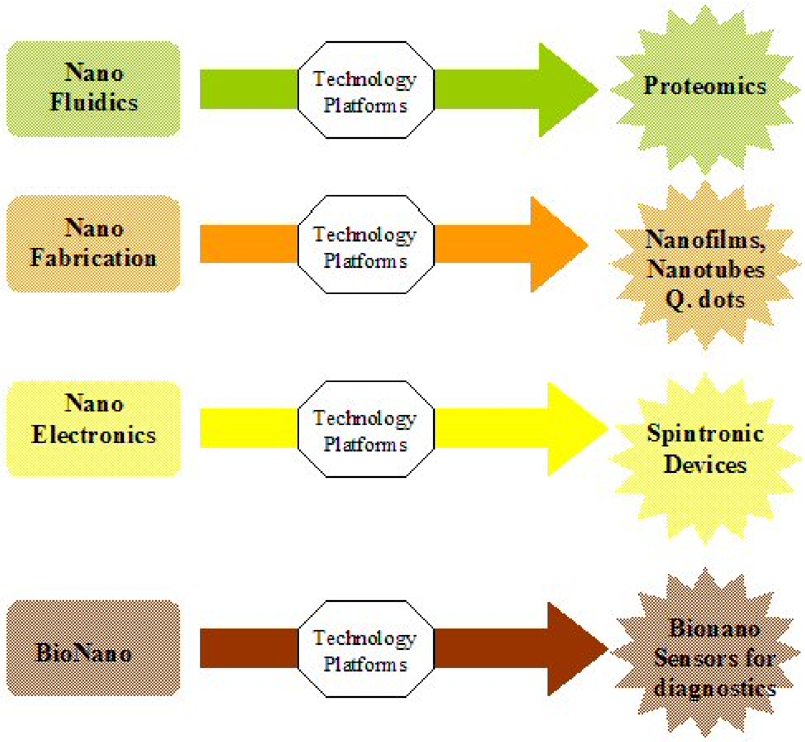

Figure 1: Examples of nanotechnology chains (as they occur at MESA+ Institute of Nanotechnology, University of Twente).

A prospective filière analysis would show the need for such technology platforms to be located near a research centre or university. The high investment of monetary and human

---

supply and sanitation, plant genomics and biotechnology, mobile and wireless communications, innovative medicines, aeronautics, embedded systems and steel."

capital into such technology platforms, and the possibility of many various diffuse technology chains to cross at this technological platform, means it is attractive to locate the various technology platforms at the same location, near skilled workforce (a workforce that evolves with the evolution of the technology platform). Small and large companies could then locate themselves near this agglomeration of technology platforms and skilled workforce. We can actually see this happening in and around the MESA+ Institute of Nanotechnology in Twente.

Figure 2 visualizes how the technology chains can cross if there is a generic technology platform combining the specific platforms relevant for each of these chains. Because of the shared need to work at the 1nm to 100nm scale, and with the instrumentation that is now in place, there are clear advantages of such a generic platform. In other words, co-location, once started up, may lead to further activities in research, in start-up firms, in technology transfer more widely, which contribute to technological agglomeration.

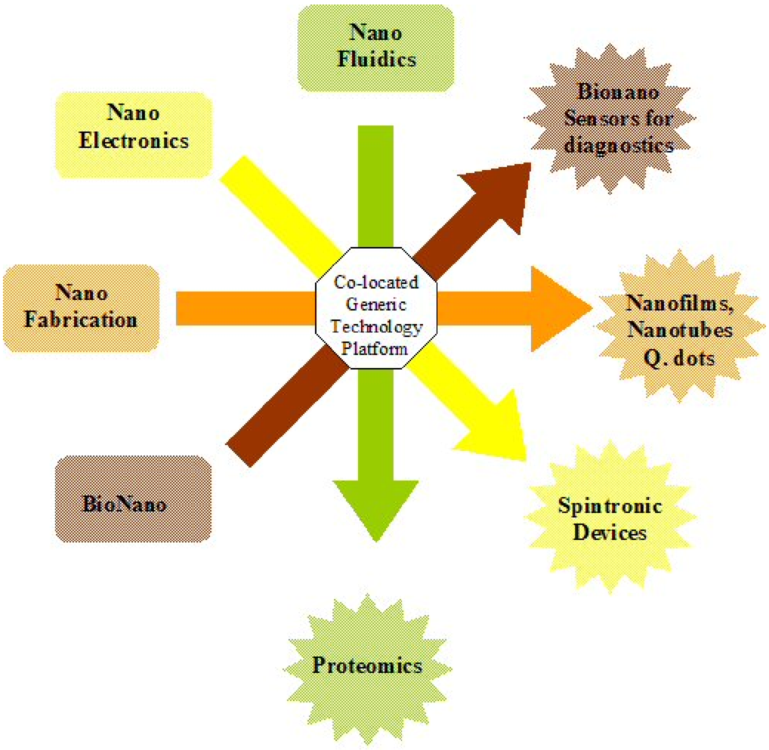

Figure 2: The crossing of chains at in at the collected technology platforms housed in the MESA+ TechPark

There will be path dependencies, in the sense that earlier investments and competencies shape what can be done later. The diagram in Figure 2 shows how Twente is enabled and constrained by the technology chains it can participate in. The two other main centres in the Netherlands, Delft and Groningen, have their own mix (with emphasis on nano-electronics and bio-nano, respectively). In general, different collections of technology platforms which are co-located enable cutting edge nanotechnology research in specific directions, as well as sunk investments which might constrain further change if there are too little resources to create new possibilities.

This discussion of possible agglomeration has highlighted technical aspects, and may therefore be read as suggesting that developments are technology driven. Indeed, in a sense, there is technical shaping, because not everything is possible. On the other hand, what is possible (or turns out to be possible) also depends on how much effort is invested by various actors. Thus, the present analysis of technology chains and platforms must be embedded in a case study of how such technical infrastructures and coordination patterns actually emerge. That is the subject of the next section. In the subsequent section, a contrasting case study, of nano-electronics in the Grenoble area is presented.

4. Emerging distributed technological agglomeration in Twente and in the Netherlands: a case study

The case study of the emergence of MESA+ in Twente and the national nanotechnology consortium "NanoNed", in which the director of MESA+, David Reinhoudt, played a major role, has various interesting aspects including institution building and its intended and unintended effects (Mangematin et al. 2005).

MESA evolved from an earlier conglomerate of groups and institutes located at the University of Twente, with research in the general area of sensors, actuators and micro-systems. By the end of 1999, further mergers with electronics, optics, and materials research groups led to the establishment of MESA+, with special investments in extensive clean room facilities and linked to a TechPark (itself building on predecessors from the early 1990s). This gradual convergence of fields and the eventual uptake of the 'nanotechnology' banner had much to do with the availability of overlapping technology platforms and the possibility of their expansion – which required institute leaders with particular entrepreneurial characteristics. The competencies built up over the last 20 years include microfabrication, microfluidics and sensors and actuators. In addition MESA+ has high international visibility with its embedded in a number of networks of excellence, many international collaborations and the inclusion of both commercial and scientific directors in a number of international consortia.

One sees some technology agglomeration occurring. For MESA+, spin-offs from the University have become an integral part of micro and nano developments in the region. In the

University of Twente research into microfluidics and lab-on-a-chip revolves around the manufacture and manipulation of chip devices both in silica and polymer. Over the last 25 years, University of Twente has built up skills in micromachining to fluidic chips, leading to two spin off companies (LioniX and MicronIt) who develop and produce fluidic chips. The production of the chips occurs in the university cleanroom facilities (which are essential for any nanotechnology developments) which are rented by the two companies. 33% of time of the cleanroom time is rented to companies, limiting the time available for ongoing research at the University of Twente. The companies cannot go elsewhere because of the large costs of such a cleanroom facility, but also because of the skilled workforce which has grown over the last 20 years.

In this particular case, the location of companies that produce chips on demand, and the mixture of other small companies, which have expertise in thin films, microsieves etc. along with research lines in MESA+ (see figure 2 on crossing research lines) enable the region flexibility within the field of micromachining.

In Groningen, facilities related to preparation, manipulation and detection of cells and biomolecules dictates the focus of this region. In Delft, investment at the Kavli Institute and TNO-TPD in lithography developments aligns the focus here. There is a mutual positioning of the institutes involved, Groningen as a hub for bionanotechnology, Twente for nanomaterials and manufacture, Delft for nanoelectronics etc.

Small microtechnology and nanotechnology companies, mainly start-ups, are playing a role in the regions, intertwined with the workings and evolution of the technical platforms. For example, in Twente start-ups are at the moment both users of facilities and providers of service. From interviews with LioniX and MicronIt, they remain small because there is little demand for their service at the moment since they provide tools for R&D, whereas when the "killer applications" arrive, expansion would be possible and such links are in development. Involvement of big firms (none of the candidates is at present active in nanotechnology) in the regions remains very low. This is a contrast with the Grenoble region (see next section), where dominant technology chains cluster around nanoelectronics, and large companies (from the semiconductor industry and related to lithography evolution) are strongly involved. And collaborate because of the large costs and high uncertainty. The difference stems from the different nanotechnologies involved, in a process of co-evolution of technical infrastructures and platforms, and industry structures (and regional incentives).

In parallel to these developments, and building on them, a series of initiatives were taken at the national level which would lead, after a number of shifts, to the present governmentfunded R&D consortium NanoNed. The original aim was to create a stronger position for the three partner centres from the universities of Twente, Groningen and Delft, in which provision of advanced technical infrastructure was to play a key part. From the 2000 “Masterplan Nanotechnology” onward, a distributed NanoLab, i.e. facilities to be located in the three centres, featured in the plans and proposals. This can be seen as a generic technology platform, not co-located (as in Figure 3) but coordinated across a few locations. Because proposals need to present a coherent picture, technological agglomeration possibilities were outlined, as promises to be realised. This then shaped further interactions and negotiations.

Shifts occurred to address resource mobilisation opportunities, in particular the expansion of the original group of three centres with a division (TPD) located in Delft, of the national applied research organization TNO, then with centres in four more universities (necessary to avoid accusations of preferential treatment of the original three centres), and eventually also Philips Company. Alignment of the various participants was a challenge, which was met (even if precariously) through institutional entrepreneurship of David Reinhoudt and others, and the promise of major funding. Important also was the need to achieve some semblance of coordination between participants who otherwise might see themselves in outright competition. This was done by positioning participants according to their specializations with cross-cutting “flagships” at the consortium national level. NanoLab continued to be a core element, with some 35% of the envisaged resources of the consortium devoted to it. Still to be located at the three main centres, but offering access to other NanoNed participants.

Table 1 below shows how NanoLab was presented in the proposals (2000-2003), emphasizing existing competencies and the promise of creating four overlapping generic technology platforms. Which would, hopefully, lead to technological agglomeration.

MESA+ focuses on the research and realisation of complex materials, devices and systems, on the processes used for the production of these and on the integration into complex devices and complete systems. Thus it aims to become the Dutch hub for nanofabrication.
MSC+ / Biomade has a fast intensifying focus on the development of (bio)molecular (nano) electronics through a combination of fundamental and applied research. Using the present infrastructure, new functional molecular elements and materials are designed and synthesized. Within the NanoLab NL programme, the MSC+ / Biomade infrastructure is designed to function as: the Dutch centre for bottom-up (bio) molecular electronics and functional (bio) molecular nanostructures. Local organizations putting effort and in such a facility MSC+, Biomade, and the Groningen Academic Hospital (AZG).

DIMES has expertise in the field of Micro- and Nano-electronics, mostly using cryogenic techniques, and expertise in Nano-fabrication in many applications. With NanoLab NL, DIMES will provide a facility for nano-fabrication for broad use (and for all sorts of material-systems), using high resolution e-beam lithography, different wet processing, oven-processes, thin film growth, dry-etch, and all sorts of nano-inspection techniques.
TNO TPD is primarily focused on production and analysis instrumentation on behalf of mass-fabrication of nano-chips. For this type of research, one needs to be able to measure, develop and experiment on (sub) nanometer scale. Within NanoLab NL the aim is the development of competencies in lithography.

Table 1: Investment and consolidation plan for instrumentation within the NanoLab NL programme. (edited version of text from NanoNed proposal to ICES-KIS 2003)

Even at this early stage in the NanoLab project we can see coordination by the enrolment of the original four members of NanoLab of Philips with the aim to coordinate facilities across the Netherlands[9].

At the end of 2005, NanoLab has invested 20% of the €90 million budget in the infrastructure has already been mobilised. The project has stimulated larger integration/coordination by the inclusion of Philips NatLab which has now joined NanoLab and is part of the decision making structure for the coordination of investments.

The five representatives (MESA+, DIMES, TNO, MSC+ and Philips) who form the board of NanoLab will coordinate the final investments during 2006. This includes the decision for investments and tariffs for use. Thus, it is not just a matter of getting new resources and dividing the spoils. Certain coherence at the level of technical infrastructures is intended.

Tensions remain, however, and not just between the university groups. Philips Company, formally part of the NanoNed consortium, continues to pursue its own interests, such as the growth of the research campus it has created on its premises and its avowed goal to push for a micro- and nanotech triangle between Eindhoven (where major research labs are located), Louvain in Belgium (with IMEC) and Aachen in Germany. As Philips Company phrases it:

> "Initiatives by governments, industries and knowledge institutions are rapidly transforming the region between Aachen, Leuven and Eindhoven from an industry-based area to a

[9] Source: information from members of the NanoLab board.

technology- and knowledge-based economy with potential to rival some of the world's most prestigious regions of excellence." *Philips Research Password*, 19 (April 2004).

One could speculate about a further form of distributed technological agglomeration, now at the level of the "Low Countries" (Netherlands, Belgium, and the German lower-Rhine region).

5. Orchestrating technological agglomeration in Grenoble, a second case study

While the Twente/Netherlands/Low Countries case can be characterised as distributed, with coherence across a variety of technological platforms emerging because of promises (made to mobilize resources) that have to be implemented, the Grenoble case builds on earlier coherence (in micro-electronics) and further expansion, in particular through the Minatec project led by Jean Therme, defined by Delemarle (2005) as an institutional entrepreneur.

During the early 1980s, LETI (The National lab dedicated to Microelectronic research applications – similar to the US Department of Energy), Thomson Semiconductor (a national leader at this time) and the Universities of Grenoble allied to develop research and development capabilities to be able to design and produce wafers of 100mm. They set up shared clean rooms for R&D while production facilities have been installed in the neighbourhood of Grenoble to make the transfer of knowledge and know how between R&D and production facilities easier. During the 1990s, they enlarged the consortium to include France Telecom Research Centre (also located in Grenoble) and to build larger research facilities dedicated to silicon applications, optronics labs and software security (cryptography). Dedicated research and training facilities which belong to different public research organisations (namely LETI, Universities of Grenoble and CNRS – Centre National de la Recherche Scientifique) are spread out within the scientific polygon (small perimeter of around a mile). Actors agreed to share access to the technological platforms and to design rules to manage intellectual property rights, to share the costs of running such platforms (pricing) and to plan the renewal and up-date of existing facilities as well as the development of new ones. Some of these facilities have been used by start-ups such as Soitec to develop their technologies and became common labs between LETI and firms.

In the late 1990s, a further step was conceived: Minatec (a building as well as a collaborative project) promoted by LETI, and in particular its then head Jean Therme. Minatec has been a project aiming at promoting the scientific, technological and economic development of nanotechnologies and is now an umbrella which covers different public research organisations including LETI, Universities of Grenoble, CNRS and other public labs. Minatec is based on four pillars: a continuum of research organisations, from universities to industry, including LETI as a bridge between basic research and industry; training, with large university campus where engineers and scientists are trained; a dense network of technology based firms be large multinationals such as Philips or Motorola or recent start-ups like Trixell, Xenocs or Soitec. The fourth pillar is the agglomeration of technological platforms. Indeed, based on the construction on new building and on the creation of up-dated technological platforms, it aims at developing micro and nanotechnologies for miniaturized devices for the citizen (microelectronic chips, flat panel displays, optical storage devices CD, DVD, optical microsystems and nanophotonics devices, biochips). The architecture of the buildings has been designed so as to encourage close links between upstream, technology and applied research allocating a central position to technological platforms. These technological platforms occupy 20,000 sq meters as a whole. They have been set up by the scientific (firms and academia) community which opted to share specific tools of increasing sophistication. Minatec groups some of them together and plans to up-grade them[10]. It also builds on the organisation of shared platforms to organise access and pricing. The Advanced Microelectronics Project centre (CPMA) enables it to access LETI resources such as the PLATO technology platform (Plasma technology, Lithography: EUV, Nanoimprint, Dielectric materials, Nanomaterials (Si, Ge, Magnetics) and Near field microscopy), the Very Low Temperature Research centre (CRTBT), the Centre for Basic research in condensed materials and the Nanofab which is specialised in the nanofabrication of objects larger than 50nm by particle based (electron and ion beam) lithography, deposition and etching (Minatec Newsletter, July 2003). It is a keystone of a large number of scientific projects in nano-optics, nanomagnetism or nanoelectronics. It also includes the CIME (Interuniversity Microelectronics Centre) which is the largest platform in France. It is a state of the art platform of 9,000 sq meters dedicated to teaching and research on silicon Microsystems and heterogeneous systems (Minatec Newsletter, January 2004).

The organisation of the work around the different and coupled technological platforms fosters pluridisciplinarity and problem solving approaches. Minatec newsletters (www.minatec.com) emphasise the linkages between the research facilities, research and training. More than 500 engineers are graduated each year and new courses have been designed to stimulate nanotechnology understanding and competencies (systems on chip, biochips, etc.). In

[10] Installation of these up-graded facilities will take 3 months and will commence in March 2006.

collaboration with Politecnico de Milano, and Ecole Polytechnique de Lausanne, University of Grenoble launched the first international engineering degree in Nanotechnology in 2004. Each of the quarterly newsletter reports on summer schools on nanosciences and nanotechnologies organised. About 4,000 employees are working in Minatec, including 1000 students from Grenoble universities and 2,000 researchers, engineers and teaching staff.

Minatec benefits from the presence of major European facilities, such as Institut Laue Langevin (ILL, neutron source), the European Synchrotron Facility (ESRF), the European Molecular Biology Laboratory (EMBL) and the Grenoble High Magnetic Field Laboratory (GHMFL) enabling atoms to be observed in fine detail and experiments to be performed which are essential to progress in nanosciences. They are located nearby (less than ½ miles away).

Promoted by LETI and universities of Grenoble (especially the engineering, physics and microelectronics departments), it aims at placing Grenoble nanotechnology as an international centre of nanoscience (Minatec newsletter n°5, January 2004). Minatec emerged from different public research organisations and universities as a hub to produce simultaneously basic research and targeted collaborations with industries. Minatec has been institutionalised during the last five years (Mangematin *et al*., 2005). The institutionalisation process builds on the existing platforms to cement local collaborations amongst actors from different institutions.

However, Minatec is mainly a public institution initiative. Meanwhile, firms around Grenoble have grown and have decided to realise a joint venture so as to share the costs and the risks in nanoelectronics fabrication. Around SGS Thomson (afterwards, ST Microelectronics), firms allied to develop a new labfab to produce wafers around 200nm. In 2000, the alliance grew up, including ST Microelectronics, Philips and Motorola to build a new labfab to deal not only with submicronic like in the previous generation but also with nanoelectronics to produce wafers of 200/300 mm. in the same time, one of the world leader in electricity, Schneider Electric decided to set up a new research centre to benefit from the spillovers and from the infrastructure around Grenoble.

In 2005, the French government labelled the new ensemble which groups Minatec, the fabrication alliance between STMicroelectronics, Philips and Motorola named Crolles and the Schneider new research centre as a world class Pole de competitivité.

There is overlapping technological agglomeration. Minatec projected, and now implements, agglomeration of facilities. Characterisation facilities are an important component, and the idea of “common labs” including special IPR rules is pushed by Jean Therme.

The other part of the picture is the strong presence of key players in micro/nano-electronics. In addition to the existing facilities, there is the question what will happen next: work towards the next integrated technological platform, or stepping out of the race altogether. The Crolles 2 production facility (some 50 of such facilities worldwide) is in place. Actors are already projecting a next “generation”, Crolles 3 (of which there will be some 20 worldwide), negotiate and struggle about what is to be done, who should take the lead etc.

What we sketched here is the dominant dynamic in the Grenoble region, and one which clearly shows the strong role of technological platforms and evolving industry structures which now need nodes where synergies are exploited. There is other development, e.g. in bionanotechnology, which are still disperse but do show emerging technology chains anchored by more or less generic technology platforms (cf. the Twente/Netherlands case).

6. Conclusions and discussion

The cases of Minatec and MESA+ illustrate the on-going creation of technological agglomeration. The agglomeration process builds on existing technological facilities, filling the gaps amongst existing facilities, expanding the breath of the existing competencies. By linking the dedicated platforms (see fig 1), it builts the technology chains accross platforms and thus transform the network of decidated facilities into a generic technology platform combining the specific platforms relevant for each of these chains. It modifies the nature of the existing competencies and technological offer, within a specific area. For nanotechnology research in particular, technology platforms and their co-location are a pre-requisite for nanotechnology research and agglomeration of such platforms are both a means and outcome for institutional entrepreneurs to mobilise resources, build networks and construct regional centres of excellence in nanotechnology.

Institutional entrepreneurs like J. Therme and D. Reinhoud appear to have to act at different levels (organizational, regional, national) at the same time. Their action is progressive and incremental. They first mobilize European support to convince local and national levels before actual cluster building occurs. They build new platforms which agglomerate to the existing ones to form a technological agglomeration which enrichs technological offer from the local area. The social and technical arrangements of a regional centres for nanotechnology both enable and constrain the ongoing activities and research lines that can be followed. Technological agglomeration is visible in the nature of subsequent activities, in the shape of the networks that evolve. One can also speculate about the effect of functioning technological platforms on the convergence of scientific disciplines. While co-location of the technology platforms is the important and recurrent phenomenon, there are different routes. In Grenoble, in the Minatec project, Jean Therme (and his allies) pools existing infrastructure in the neighbourhood, upgrades those that are needed and adds new ones. In the Netherlands, the strategy of key actors, with David Reinhoudt in the lead, is to reinforce existing competencies by overlaying the facilities with funding to key focal areas, leading to different nano-hubs.

The transformation from an addition of platforms to a technological agglomeration changes the position of the local actors within networks and enables the creation of new linkages and alliances as actors can mobilise a wider variety of techncis and competencies.

Even if the effects on the technological offer are quite similar, the local arrangements differ and business models of platforms remain unsetteled: In the two cases, differing strategies are visible. There are tensions for clean room time, dictated by the policy of 33% of the time being made available for small companies. Expansion and diversification in research and in spin offs is constrained by the limited time, and enabled as well as constrained by the embedded skills in the generic technology platform. This is compounded by responsibilities of the local hubs to the national NanoLab arrangement where more of local research institutes time is limited by the sharing of facilities. Basing on the MESA+ case as an indicator, one may see small (perhaps larger) companies agglomerating around these facilities, spinning out of the local research centres and providing a service within the facilities (like LionIx and MicronIt).

In Minatec the organisation of the clean room and related facilities is different: there will be dedicated staff to do fabrication and analysis as a service to a customer. The actual co-location of equipment and the relations with the original institutions and their staff will not be easy though.

Thus, the further development may not be conforming to the promises and projections that were made. But it is clear already that there will be effects. Links between universities, public research institutes and firms (small, medium and large) become more important. Regional actors and policy makers become part of the techno-institutional dynamics and changes in industrial networks.

Clustering on the basis of technology platforms does not only shape emerging nanotechnology regions, but is also important for the distribution of hubs and Poles de Competitivité at the national level and probably also at the European level. Hybrid roles merge, for start-ups (see LioniX and MicronIt), and in coordination of facilities with industry (Philips and examples from Minatec) as both users of facilities and providers of a service.

7. References

Agrawal, A. and Cockburn, I., The anchor tenant hypothesis: exploring the role of large, local, R&D intensive firms in regional innovation systems, International Journal of Industrial Organization 21 (2003) 1227-1253.

Amit R, Zott C. 2001. Value creation in e-business. *Strategic Management Journal* **22**(6-7): 493-520

Arie Rip, 'Introduction of New Technology: Making Use of Recent Insights from Sociology and Economics of Technology,' *Technology Analysis & Strategic Management 7*(4) (1995) 417-431

Autant-Bernard C, Massard N, Mangematin V. 2006. Creation of high tech SMEs: The influence of local environment. *Small business Economics* **Forthcoming**

Chang, H., Cooke, L., Hunt, M., Martin,G., McNelly, A., Todd, L. 1999. Surviving the Soc Revolution: A Guide to Platform-Based Design, Springer Press

COM(2004)353 European Commission Communication: "Science and technology, the key to Europe's future - Guidelines for future European Union policy to support research"

Delemarle A. 2005. Beyond the super hero's myth: the genesis of the institutional entrepreneur's discourse. *WP*

Feldman M, Ronzio C. 2001. Closing the innovative loop: moving from the laboratory to the shop floor in biotechnology manufacturing. *Entrepreneurship and Regional Development* **13**: 1-16

Gawer A, Cusumano MA. 2002. Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation. Harvard Business School Press: Boston, MA

Hackett, Edward J., David Conz, John Parker, Jonathon Bashford, Susan DeLay. Tokamaks and turbulence: research ensembles, policy and technoscientific work. Research Policy 33 (2004) 747–767

Håkansson, H. and Snehota, I., (eds.) (1995), *Developing Relationships in Business Networks*, London; Routledge.

Keating, Peter, and Alberto Cambrosio, Biomedical Platforms. Realigning the Normal and the Pathological in Late-Twentieth-Century Medicine, Cambridge, Mass.: MIT Press, 2003

Langlois, R. N. and D.A. Savage (2001), "Standards, modularity, and innovation: the case of medical practice," in R. Garud and P. Karnoe (eds), Path Dependence and Path Creation. Lawrence Erlbaum Hillsdale, NJ, pp.149-168

Lüthje, B., "Making Moore's Law Affordable" - Modularization and Global Networks of Innovation in Chip-Design.Paper for workshop "Bringing Technology Back In", Köln, 10-11 March 2006

Mangematin, V., Rip, A., Delemarle, A. and Robinson, D. K. R. (2005) The Role of Regional Institutional Entrepreneurs In the Emergence of Clusters in Nanotechnologies, paper submitted to *Organization Studies*.

Peerbaye, Ashveen (2004), *La construction de l'espace génomique en France: La place des dispositifs instrumentaux*, Cachan: École Normale Supérieure de Cachan. Thèse de Doctorat.

Tassey, Gregory (1991), 'The functions technological infrastructure in a competitive economy', *Research Policy* 20(4), 345-361

Tatikonda, M.V., ‘An Empirical Study of Platform and Derivative Product Development Projects’, *J. Product Innovation Management* 16 (1999) 3-26.

Zucker LG, Darby MR, Armstrong J. 1998. Geographically Localized Knowledge : Spillovers or Markets? *Economic Inquiry* **36**(1): 65-86

Zucker LG, Darby MR, Armstrong J. 2002. Commercializing Knowledge: University Science, Knowledge Capture, And Firm Performance in Biotechnology. *Management Science* **48**(1): 138-153